



Building European nuclear competence through continuous advanced and Structured Education and Training Actions

(ENEN2plus Horizon Europe Project n°101061677)

**Work Package 1
Human resources analysis in the nuclear sector**

Executive summary report, analysis, and recommendations

CONTENTS

CONTENTS	1
1. Introduction	3
1.1. Nuclear sector context	3
1.2. ENEN2+ project.....	4
2. TF1.1 Human resources needs in the nuclear industry.....	6
2.1. Nuclear industry context and challenges	6
2.2. Methodology of the TF 1.1 study	7
2.3. Key outputs of TF 1.1	8
2.3.1 Quantitative outputs	9
2.3.1.1. Operating NPPs (existing and future).....	9
2.3.1.2. Building new NPPs.....	10
2.3.2 Qualitative outputs	10
3. TF1.2 Human resources needs in research, safety, and waste management.....	12
3.1 Nuclear research, safety and waste management organizations context and challenges.....	12
3.2 Methodology of the TF 1.2 study	13
3.3 Key outputs of TF 1.2	14
3.3.1 Quantitative outputs	14
3.3.1.1. Nuclear Research organizations	14
3.3.1.2. Safety organizations	14
3.3.1.3. Waste Management organizations	15
3.3.2 Qualitative outputs	15
4. Task Force 1.3 HR requirements in non-energy applications	16
4.1 Non-energy applications context and challenges.....	16

4.2	Methodology for TF 1.3 study	18
4.3	Key-outputs of TF 1.3.....	19
4.3.1	Medical Physics	19
4.3.2	Radiopharmacists and radiochemists	20
4.3.3	Nuclear applications in the environment sector	20
4.3.4	Nuclear applications in the space sector.....	21
5.	Summary and aggregation of key figures, simplified model within the WP1 perimeter	21
6.	Discussion and pain points.....	23
6.1	Limitations due to data collection and data quality	23
6.2	Consistency of results: simplified benchmarking approach	24
6.3	Discussion of qualitative results	26
6.3.1	Direct and indirect jobs	26
6.3.2	HR skills are difficult to categorize	26
6.3.3	HR needs are strongly time dependent	27
6.3.4	Ratio of new recruitments to compensate for retirements	27
7.	Recommendations	28
7.1	General recommendations.....	28
7.1.1	Recommendations for Industry.....	29
7.1.2	Recommendations for E&T providers	30
7.1.3	Recommendations for policymakers.....	31
7.1.3.1	At national level.....	31
7.1.3.2	At EU level	32
7.2	Other recommendations from the reports of the taskforces.....	34
7.2.1	For industry	34
7.2.2	For safety organizations (regulators and technical safety organizations).....	34
7.2.3	For universities and research organizations.....	34
7.2.4	For the medical sector.....	34

1. Introduction

1.1. Nuclear sector context

There are currently 109 reactors in operation within EU27+UK perimeter, able to deliver 102,5 GW, and 110 reactors permanently shut down (87 under decommissioning). Nuclear plants provide almost half of the low-carbon electricity production in the EU. Moreover, during geopolitical crises, nuclear power can provide increased independence and resilience. The EU's nuclear fleet accounts for a quarter of the world's nuclear power production. In the UK, nuclear energy represented 14.2% of the country's electricity production in 2022, while in the EU nuclear accounted for 24.57% (with high variability according to countries: from 0% to 74%) of the electricity production in 2020.

Several countries intend to extend of the lifetime of their current nuclear fleet (Bulgaria, Czech Republic, Croatia, Slovenia, Finland, Hungary, Netherlands, Romania, Slovakia). Belgium is currently discussing the future of Doel 4 and Tihange 3, despite previous commitments to phase out by 2025. In France, the *Grand Carénage* programme is ongoing to extend the lifetime of the current fleet. Several countries are planning or considering new nuclear power plants: Bulgaria (two at Kozloduy, two at Belene), Czech Republic (Dukovany units 5&6 announced, Temelin 3&4 under consideration), Estonia (first nuclear power plant by 2035), France (up to 14 new reactors by 2035, 6 planned, 8 under study), Hungary (two new units Paks II), Netherlands (steps to build two new units), Poland (first reactor planned for 2033), Romania (Cernavoda 3&4), Slovakia (new unit at Bohunice), Slovenia (considering the construction of a second unit), Sweden (planning to replace aging reactors), United Kingdom (currently constructing Hinkley Point C with 2 EPR, considering 8 new units to reach 25% of its projected electricity demand by 2050 with 24 GW nuclear). In addition, several countries are also considering the SMRs option (Bulgaria, Czech Republic, Finland, France, Italy, Netherlands, Poland, Romania, Sweden, United Kingdom).

These new projects, designed with high safety characteristics and an expected lifetime of more than 60 years, would maintain the current 25% share of nuclear energy in EU electricity generation. Nuclear energy will therefore continue to be a major component of carbon-free electricity generation in Europe, as confirmed by the meeting of the Nuclear Alliance countries in Paris on 16 May 2023. Ministers and high-level representatives from 16 countries, meeting with the European Commissioner for Energy, highlighted the essential contribution of nuclear energy, complementing renewable energy, to the collective achievement of climate neutrality by 2050 at the latest. They insisted that nuclear energy provides controllable capacity and significantly supplies Europe with electricity without resorting to fossil fuels. They consider that nuclear energy could provide up to 150 GW of electricity capacity to the EU by 2050, representing 30 to 45 large new reactors and small modular reactors (SMRs). The Nuclear Alliance, in its press release issued following the meeting held in Bratislava on 7 November 2023, underlines that *“the European Union is currently facing a significant risk of losing expertise and skills in the nuclear field, due to an ageing workforce and a drop in the number of new graduates in nuclear science and engineering”* and welcomes in this context the Euratom ENEN2plus project.

However, these forecasts of new construction are affected by a high level of uncertainty, in an unstable geopolitical situation. Europe is facing a war on its doorstep, with major consequences for the energy resilience of Member States. In addition, new projects face increased demands for transparency from public opinion, amplified by the impact of social media.

The nuclear sector, including for non-energy applications, implements complex technologies, which require specific skills. All nuclear activities are based on a set of scientific, technical, industrial, and legal expertise, and therefore require sufficient human resources and skills, evolving over time. It must

integrate the most recent technological advances, particularly in the digital sector, while valuing feedback from existing facilities. All nuclear activities, whatever the possible divergent political choices for each country, are carried out within a strict legislative and regulatory framework (licensing process, on-site inspections, etc.) and are developing in increasingly challenging competitive market conditions. Different stages, such as construction, operation, maintenance, and decommissioning, require specific skill sets at different times. With the existing fleet's continued operation and new build projects, there will be a strong demand for a highly qualified workforce. Some EU countries have decided to phase out nuclear power. It is also necessary for these countries to have nuclear expertise in decommissioning and waste management to properly decommission facilities that are or will be shut down. Nuclear is an international industry, capacity building is a national challenge that will require international cooperation. Across Europe, HR will need to be trained, and nuclear technicians and engineers will be mobile to move from one construction site to the next to meet the high demand, having the right resources, at the right place, at the right time.

The significant need for new HR is obvious. In general, nuclear science and technology finds it difficult to be perceived as a sufficiently attractive environment for a career. The decline in the interest of the younger generation in nuclear power is particularly affecting Member States where the phasing out of nuclear power in the electricity mix has already been decided. In addition, a significant loss of manpower in the nuclear sector may occur due to the attractiveness of regions outside the EU where new nuclear projects are engaged in a very dynamic way.

1.2. ENEN2+ project

Ensuring that the European nuclear sector has the right people, with the right skills, at the right time, at the right place, is crucial to avoid issues with new build projects, including delays and cost overruns. This is the *raison d'être* of the ENEN2+ project, which aims to strengthen European nuclear skills through continuous advanced and structured education and training. The ENEN2+ project, launched in June 2022, is led by ENEN (project leader Gabriel Pavel, ENEN), and is divided into 8 Work Packages (Figure 1).

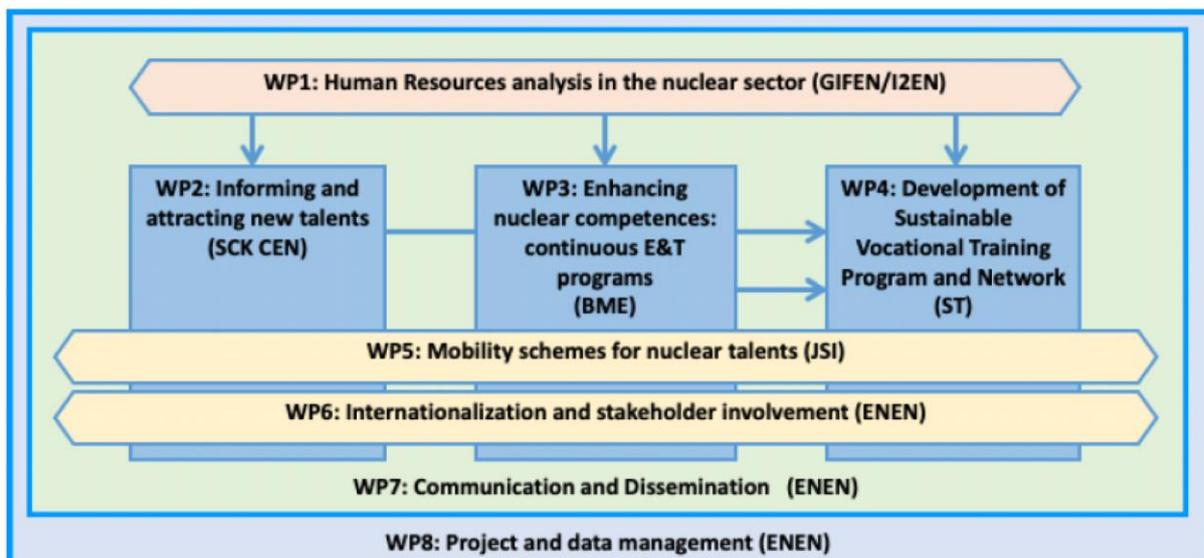


Figure 1: ENEN2+ project divided into 8 Work Packages

Such an analysis should make it possible to anticipate needs and identify possible gaps between local training needs and capacities (initial and continuing). Conducting this analysis at EU level, rather than on a country-by-country basis, is a way to minimize and mitigate risks in a logic of overall EU resilience. It is also a way to consolidate both the EU's low-carbon energy strategy and the EU's leadership in the face of international opportunities for the development of nuclear technologies.

The horizon for the construction of new nuclear facilities extends beyond the ten years that constitute the horizon set for the ENEN2+ project. The demand for clean energy, the increased range of non-power applications, as well as long term perspectives related to nuclear fusion and the ITER project, are likely to ensure that the nuclear sector will continue to evolve and expand over the next ten years and beyond. However, such increase is likely to vary in the different nuclear subsectors, depending on national policies and programmes. The human resources for which it will be necessary to recruit training in anticipation could therefore be underestimated. It should be stated that this report does not cover human resources needs necessary for the development of the European nuclear fusion activities.

I2EN is responsible for leading Work Package 1 (WP1 leader Karen Daifuku, I2EN Executive Director). WP1 aims to assess human resources and skills' needs at the horizon 2035, by identifying possible deficits between supply and demand, over a 10-year horizon on the EU27 + UK perimeter. WP1 is an important pillar of the whole project since its results will be used as input data by the other work packages of the project. Its conclusions and recommendations will also be carefully considered by political, governmental, industrial, and academic leaders in European countries engaged in new nuclear projects.

A full understanding of the workforce size, its needs in terms of competences and possible mitigating measures can only be established through involvement of all relevant stakeholders (ministries responsible for nuclear programmes, industry organizations, regulatory authorities, technical safety organizations, research and training infrastructures and academia). This is the reason why the scope of WP1 was covered by three task forces to specifically analyse human resources needs of:

- TF 1.1: European industry
- TF 1.2: the areas of R&D, waste management and safety
- TF 1.3: non-energy applications (including in the medical sector)

TF 1.2 and 1.3 submitted their reports on 30 May 2023 after a year of work involving more than 10 experts in 8 countries. Deadline for TF 1.1 to submit its report is by November 2023. The very large scope of stakeholders could obviously not be fully explored during the duration of the study. Nevertheless, best efforts of all participants have allowed to draw conclusions and make recommendations.

The present document is the summary report of WP1, under the responsibility of I2EN and approved by the respective task force leaders. It aims to address methodological aspects, to sum up main outputs and recommendations of the three task forces' reports, and to introduce some additional comments, methodology concerns and discussion of results. It also highlights the interactions between the three task forces, exhibiting common recommendations to the industry, policymakers and E&T organizations.

2. TF1.1 Human resources needs in the nuclear industry

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2.1. Nuclear industry context and challenges

The goals to be achieved through Task Force 1.1 include providing an overview of the existing HR situation in EU27 + UK with a focus on countries participating in the ENEN2+ project, anticipating needs to 2035, providing a suitable level of details by job type according to documented job descriptions, exhibiting potential gaps between available HR and needs until 2035, and providing recommendations to the industry, policymakers and E&T organizations in order to fill the gaps through the development of targeted interventions.

The nuclear industry sustains a greater share of highly skilled employees compared to the electricity sector in general. The nuclear industry's unique safety and operational requirements necessitate a specialized skill set, and companies should actively invest in training and development programmes to ensure the availability of qualified personnel for critical roles and effective knowledge management strategies, ensuring in parallel the transfer of critical expertise and best practices among employees.

It should be strongly emphasized while the focus is usually placed on experts, nuclear facilities do not require only nuclear specialists to be maintained and operated. Experience has shown that the technicians and semi-skilled workers form a very large portion of the needed workforce.

The context of this report is driven by the changing energy concerns in the EU27 + UK perimeter, which will keep evolving in the near future. These concerns include among others the following issues and objectives:

- climate change: achieve commitments of EU to reduce the CO₂ footprint,
- geopolitics: reduce dependence on imported fossil fuels as well as increase resilience when facing consequences of political uncertainties with war at the frontiers of Europe,
- electricity use: the share of electricity in the energy mix will keep growing with electric vehicles, industrial processes, green H₂, etc.

Public opinion regarding nuclear has also evolved more favourably in some countries, which has led to policy statements in some in support of nuclear new build. The development of renewables has introduced tension on the work market in the EU for some skills, while some innovations (SMR, Gen IV, etc.) might disrupt existing business and impact HR needs for the near future. Attractiveness of the nuclear sector in competition with other industrial activities, including other energy sectors under rapid development such as renewables, is a challenge.

2.2. Methodology of the TF 1.1 study

TF1.1's perimeter encompasses the largest number of HR considered in the study conducted for ENEN2+ project. Maintain staff level and relevant skills among all industrial players of the sector is critical for the safe and secure operation of the EU27+UK existing nuclear fleet, as well as a strategic top priority concern for its future development. Complementary approaches were implemented and combined to analyse the industry sector:

- A **literature review** was conducted to assess what information is available in the public domain, determine whether the results would differ significantly from those of previous reports, and identify new trends in the present context compared to previous reports.
- A **survey** entitled "ENEN2+ on HR and skills needs in the nuclear sector" was conducted to collect data from the grassroots level. The survey's content was prepared and merged with TF1.2. To explore the perimeter of TF1.1, the survey was sent to NuclearEurope's members, which includes utilities and companies involved in the fuel cycle (front-end and back-end whereas waste management is covered in TF1.2).
- Simplified **modelling** was used to account for potential gaps in the data, checking results consistency. Existing models described in literature for HR in the operational and construction phases of NPPs were adapted.
- **Scenarios** were introduced to account for possible evolutions of HR needs for new NPP construction according to policy statements of different countries and as far as possible to account for the impact of innovative concepts such as small modular reactors (SMRs).

The scope of organizations and stakeholders that are involved in the analysis of HR needs is very broad. The report of TF 1.1 covers existing nuclear power plant (NPP) owners/operators (utilities), as well as the entire nuclear industry and supply chain, especially SMEs involved in supply chains, specific components/subcomponents manufacturers, services providers (engineering, maintenance, digital tools, etc.), and integrators (e.g., engineering, procurement and construction management, civil works, etc., for new build).

To make results easier to interpret, industrial organizations considered in the report have been classified according to their activities in the following segments:

- activity segment: utilities
- activity segment: fuel fabrication, enrichment, supply, cycle
- activity segment: design, engineering, manufacturing, and maintenance
- activity segment: transport
- activity segment: other

Four tracks were identified to analyse the workforce's skills for NPP operation:

- Reactor physics, safety, and security
- Nuclear technology, construction, and operation
- Chemistry and environment and decommissioning
- Other (support functions, procurement, administration, management system, etc.)

To make results easier to interpret, the report divides the workforce into the following 4 categories, consistently with the well-known nuclear competence pyramid:

- Experts
- Nuclear professionals
- Nuclearized professionals
- Nuclear-aware professionals.

In addition, three categories of skills have been identified to draft, in a simplified approach, trends in the demand from collected data and lead to recommendations for E&T institutions:

- General engineering
- Nuclear-specific
- Soft skills

As a compulsory first step, a skills assessment system should rely on a **commonly established skills inventory and jobs / skills mapping using qualitative and quantitative non ambiguous criteria** in terms of knowledge, know-how, behaviour, experience, and employee turnover frequency. The level of detail can vary from one job to another depending on its sensitivity. Some work has been conducted by the IAEA Technical Working Group on Training and Qualification of Nuclear Power Plant Personnel (see for instance the 2006 publication¹ aiming to provide guidance on the development and implementation of competency assessments for nuclear industry personnel) but deserves to be updated. Moreover, efforts towards harmonization of skills assessment methodologies in the EU27+UK perimeter would be welcome to facilitate future studies on nuclear workforce assessment. Skills assessment system must also define skill levels and 'in the field' know-how needed for the various jobs and determine the assessment criteria to measure the skills of staff members. Rules also need to be established to deliver certification / qualification to staff members and facilitate movements of staff members inside, between, and outside stakeholder organizations, thus contributing to people employability within the nuclear sector and more broadly to serve large projects in the country or abroad, especially among EU Member States.

The European Qualifications Framework (EQF), as recommended by the Council Recommendation of 22 May 2017, serves as a vital tool for referencing and comparing national qualifications frameworks or systems. EHRO-N has recently introduced a proposed simplified job classification for assessing the nuclear workforce, encompassing 23 job functions/competence areas for staff with higher education levels (EQF 6 to 8) and 8 job functions/competence areas for staff with higher technical education levels (EQF 4 to 5). The results of the latest EHRO-N Job Taxonomy were used to prepare the structured survey above mentioned.

2.3. Key outputs of TF 1.1

The survey was sent to 39 organizations within NuclearEurope's network yielded only **19 responses, some of which weren't fully complete, resulting in a 48% response rate. These responses only covered 8 countries** (Belgium, Bulgaria, Estonia, France, Hungary, Romania, Spain, and UK). For France and the Netherlands, the answers were provided based on a detailed parallel study conducted at the national level (respectively the Match report and Technopolis Group report).

¹ https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1236_web.pdf

The organizations that answered were involved in the following activities (some were involved in multiple activities):

- Utility (20%)
- Fuel fabrication, enrichment, supply, cycle (19%)
- Design, engineering, manufacturing, and maintenance (42%)
- Transport (11%)
- Other (8%)

2.3.1 Quantitative outputs

The nuclear sector is a significant employer, generating over 1.1 million direct, indirect, and induced jobs in the EU27+UK. In the following, we will consider only direct and indirect jobs (500,000), among which as previously said, a majority (around 380,000) employed in the industrial sector. The perimeter of Task Force 1.1 (industry) represents the largest contribution to the nuclear sector's workforce in 2023 (380,000 out of 500,000 total direct and indirect jobs), including for the 2035 forecast.

2.3.1.1. Operating NPPs (existing and future)

From the literature review (IAEA report 2022) median staffing for a single unit is near 730 jobs and near 500 for a two-unit plant. This estimation suggests a workforce of **just under jobs 80,000 workers for the operation and daily maintenance of the current nuclear reactors in EU27 + UK**. It covers mainly utilities and does not encompass the broader aspects of the nuclear industry, such as supply chains, design, components manufacturing, waste management, etc.

There will be of course a continuous need for the influx of skilled workers to replace part of this workforce that is retiring. Final numbers are highly sensitive to the value of annual recruitment rate. The value usually applied to industry is 2.5% per year. Additional demographic studies need to be conducted to check whether this hypothesis is applicable to the nuclear industry as well. It is projected that between 148,000 jobs (using a retirement rate of 2.0% per year) and 167,000 jobs (using a retirement rate of 2.5% per year) will need to be recruited by 2035 in the nuclear industry in the EU27+UK, 50,000 to 60,000 of those being direct jobs.

Even without an increase in nuclear capacity, approximately 34,000 (using a retirement rate of 2.0% per year) **to 43,000 workers (direct jobs)** (using a retirement rate of 2.5% per year) **will need to be recruited by 2035**. When taking into account additional workers leaving the nuclear sector to shift to other attractive energy sectors, **in order to maintain the necessary workforce we estimate the need for new recruitments between 76,000** (using a retirement rate of 2.0% per year) **and 95,000** (using a retirement rate of 2.5% per year) **in 2035 (direct and indirect jobs in the industry perimeter) even without an increase in nuclear capacity.**

In addition, if new nuclear power plants in the EU27+UK become operational, there will be a corresponding increase in the demand for specialized personnel to handle plant operation, maintenance, and safety, with additional needs for regulators and technical safety organizations (TSO) (see TF 1.2). **In the average scenario where an additional capacity of 10 units is assumed, which is roughly equivalent to a "reasonable" hypothesis of 10% capacity increase of the existing fleet** (not considering specificities of SMRs), **the workforce requirement dedicated to new plant operations** (once the plant construction has been completed and the reactor is connected to the grid) **might be increased by 8,000 direct jobs for utilities by 2035.**

Requirements workforce can be anticipated similar within the nuclear supply chain, potentially doubling the number of direct jobs needed. Even if some uncertainty appears in this hypothesis, we have considered for simplified analysis in the following that number of workers in “indirect” jobs category provides a good estimation of the nuclear supply chain of the nuclear ecosystem.

2.3.1.2. Building new NPPs

The size of the workforce during construction of a nuclear power plant varies depending on several factors such as the size and complexity of the plant, the contractual scheme between technology provider and plant owner, the construction method used, the level of automation and technology used, and the availability of skilled workers. For illustration, if SMRs are to be developed, required skills for construction might be focused more on components industrial manufacturing sites and less on construction sites.

According to industry estimates, **the construction of a single nuclear power plant can create a few thousand up to tens of thousands of jobs during the construction phase**, depending on the specific circumstances of the project.

The construction of a nuclear power plant is a complex and long-term process that can take several years to complete. As a result, the size of the workforce required may vary over time depending on the stage of the construction process. Estimation of the required workforce may also vary considering mobility of workers from one site to another if constructions are planned in sequence. These workers may be employed directly by the nuclear power plant owner and/or future operator, the construction contractor, or subcontractors working on specific aspects of the construction project. This is the reason why in our estimations the ratio of indirect jobs vs direct jobs has been increased (more than one indirect for each direct) when considering new NPP construction phases.

If the number of new recruitments of direct jobs in the full perimeter of industry to cope with a 10% growth ranges between 15,000 and 20,000, the corresponding number in the supply chain and diverse subcontractors (including civil works companies for example) could reach up to 55,000. A large part of these supplementary workforce has not to be composed of nuclear experts of course, and we find here again our comment about importance of technicians and semi-skilled workers.

2.3.2 Qualitative outputs

The four job-clusters introduced in the methodology of the study allow to exhibit majority (54%) of current jobs in nuclear technology, construction, and operation category (Figure 2). This is not surprising, however, when going into details, this result can be interpreted in a useful way to prepare recommendations for E&T providers.

It is an indication of the trend for main demand from the nuclear sector that is focusing on ‘nuclear professionals’, ‘nuclearized professionals’, ‘nuclear-aware’ professionals, rather than on ‘nuclear experts’ categories. In other words, general engineering comes on top of the demand rather than nuclear-specific categories of skills.

This interpretation is confirmed by results of the survey. Currently, the most sought-after jobs in nearly all the activity segments considered in the study are found in the "other" category, which includes roles like welders, fitters, boilermakers, etc. Looking ahead to the next decade, the respondents foresee the demand for jobs growing also in this "other" category. We will come back on this output, which might be considered as too imprecise, in discussion about the methodology of the study. This is

also confirmed by the fact that according to the survey respondents’ predictions, there is a noteworthy, forecasted increase in the demand for staff possessing EQF “intermediate” (4-5) qualifications.

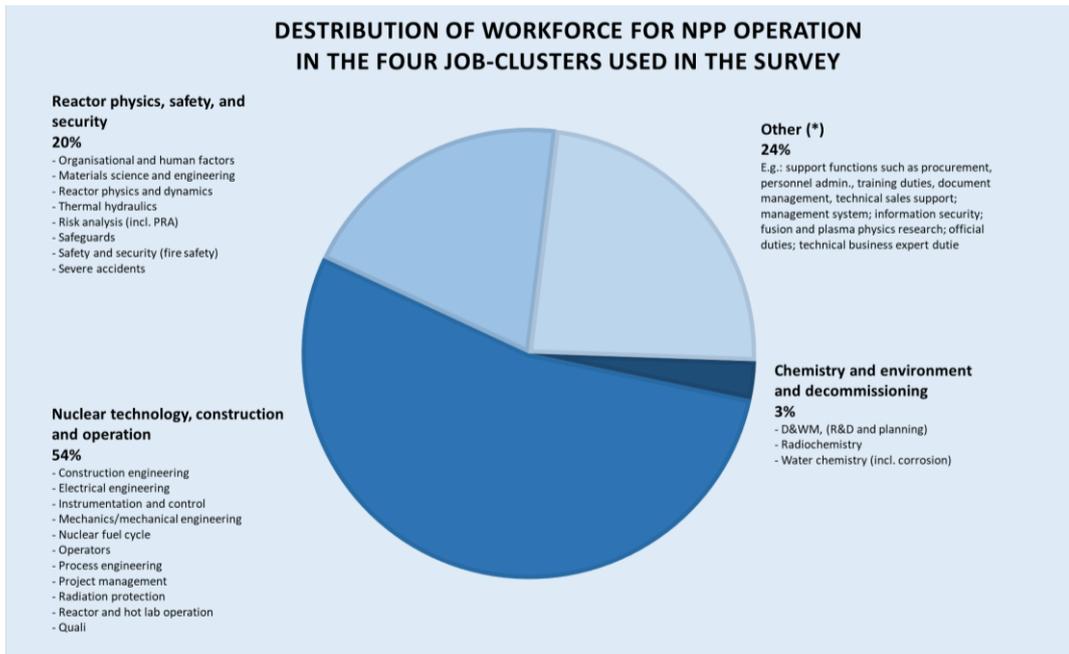


Figure 2: Distribution of workforce for NPP operation in the four clusters used in the ENEN2+ survey

(The median staffing numbers for the 43 different staff categories in the IAEA report has been aligned with the 23 job functions/competence areas used in the ENEN2+ survey.)

Alongside the ongoing strong demand within the “other” category, **project managers** emerge as the most highly sought-after position.

For the utilities’ activity segment, additionally, process engineers, reactor physics and dynamics specialists, and other types of engineers (electrical, mechanical, etc.) are in high demand. A general understanding of nuclear science and nuclear safety will be highly regarded, indicating that utilities are nevertheless actively seeking candidates with nuclear-specific skills: 48.1% of their skills needs will pertain to nuclear-specific knowledge.

In the engineering segment of activity, companies will highly value professionals with general engineering skills, crucial in the design, engineering, manufacturing, and maintenance activity segment, making up 38.3% of the overall skills demand. Among engineering disciplines, expertise in electrical and process engineering will be particularly important.

This highlights the continued importance of ensuring the attractiveness of science, technology, engineering, and mathematics (STEM) subjects and of the nuclear industry. Among students graduating in these disciplines, competition for talent between companies within the nuclear sector, and from other industries such as the high-tech or the services sectors, poses serious recruitment challenges.

Soft skills will also be in high demand in the future and will require education & training providers to adapt their curricula (see recommendations chapter), so that they can be both multidisciplinary and emphasise skills such as leadership, communication, problem-solving, to better fit with the industry’s and other stakeholders’ evolving needs. Companies will highly value professionals who possess strong

attention to detail, adaptability, ease of learning, effective communication, critical thinking abilities, accountability, and leadership qualities. These soft skills will be particularly sought after by companies involved in the design, engineering, manufacturing, and maintenance activity segment (38.3% of skills needs), and in fuel fabrication, enrichment, supply, cycle (45.8% of skills needs) activities. For utilities, soft skills will make up 33.3% of their overall skills requirements.

3. TF1.2 Human resources needs in research, safety, and waste management

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3.1 Nuclear research, safety and waste management organizations context and challenges

Although the number of professionals in the perimeter (nuclear research centres, regulatory and technical safety support organizations, waste management agencies) is lower than the number in nuclear industry, their level of expertise is high, often at the doctoral or postdoctoral level.

Research reactors deserve specific attention in this perimeter, as they constitute a significant tool for R&D in nuclear sector. The primary use of Research reactors is to provide a neutron source for research (material studies, non-destructive examination, radioisotope production for medical and industrial use, etc.). But in addition, they are easily accessible facilities for students, doctoral students, postdocs, and teachers. Therefore, they provide a large contribution to E&T for operators, maintenance and operational staff of nuclear facilities, radiation protection personnel, regulatory personnel, students, and researchers.

Current situation in Europe collected from the IAEA RDDB database, as of May 2023, shows 32 operational research reactors, 14 permanent shutdown, 4 shutdown reactors, 155 under decommissioning or decommissioned, and 4 under construction or planned (Belgium, Netherland, France, and the Czech Republic). These reactors are located in 13 countries. It is worth noticing that more than 80 percent of the research reactors are over 20 years old, or older.

Research centres and universities provide for the nuclear sector as a whole opportunity to integrate the most recent technological advances, particularly in the digital sector. Nuclear R&D is constantly evolving, and new skills and technologies may emerge. Continuous learning and professional development are crucial for the sector. Even if they are not equipped with a research reactor, and even in countries without nuclear energy, research centres and universities play an important role in strengthening nuclear skills (e.g., training of trainers). They may contribute to nuclear awareness in general in a wide range of student pathways, including in non-technical sectors (law, health, commerce, etc.). Through communication of their scientific results, they may also contribute to nuclear awareness of the general public.

All nuclear activities, whatever the possible divergent political choices for each country, are carried out within a strict legislative and regulatory framework (licensing process, on-site inspections, etc.) which must be strictly stated and controlled by safety/security dedicated organizations. Technical safety organizations (TSO's) are responsible for independent scientific and technical support to the local regulatory body regarding nuclear safety and, in some cases, also nuclear security and safeguards. A TSO can be an external organization recognized by the regulator or an internal organizational unit of the regulatory body. In the latter, support from other external partners is often necessary. These organizations, whatever their status according to each country's specific legal and regulatory framework, must be staffed with relevant personnel in number and expertise. It should be noticed that in most of TSOs some of the employees dedicate a significant part of their activity to research programmes, to keep up to date with international state-of-the-art technologies in the various scientific disciplines required by their missions.

In addition, even for the EU countries where phase-out from nuclear power has been decided, it remains necessary to have nuclear expertise in decommissioning and waste management to properly decommission facilities that are or will be shut down. Even though the primary responsibility for managing spent fuel and radioactive waste stays with the owner or license holder of the facility from which the spent fuel and radioactive waste originates, many States have created national radioactive waste management organizations (WMOs) that are responsible for developing arrangements for the management of spent fuel and disposal of radioactive waste. Others have opted for an industry approach (e.g., Finland, Sweden). In some countries, for example France, spent fuel is not considered as waste since a reprocessing industrial step allows to recover remaining usable radioactive materials they contain as well as reduce the volume of final waste. Currently there are 23 public and/or private WMOs operating in 23 EU countries and in the UK. For countries without nuclear power programmes, the quantity of waste concerned might not justify the existence of a WMO. In these cases, responsibility for such matters is taken by a national research centre, a ministerial department or other body.

3.2 Methodology of the TF 1.2 study

Data collection through a survey was chosen, with the aim of collecting data as much as possible from the field. The survey was prepared jointly with TF1.1. The part of the questionnaire which refers to TF1.2 was divided into three sections:

- Company/organization information
- Employment in company/organization and projections
- Workforce needs

For TF1.2, professions requiring formal nuclear education background (bachelor, master, PhD) were divided into three subcategories:

- Chemistry, environment, and decommissioning: nuclear waste management, decommissioning, and dismantling (including R&D and planning), radiochemistry, water chemistry (including corrosion)
- Nuclear technology, construction, and operation: construction engineering, electrical engineering, instrumentation and control, mechanics/mechanical engineering, nuclear fuel cycle (R&D, front-end, reprocessing and back-end), process engineering, project management, reactor and "hot" lab operation, radiation protection, quality management and inspections
- Reactor physics, safety, and security: organizational and human factors, materials science, and engineering (nuclear facility materials, failures, component engineering, inspections, and

lifetime management), nuclear and particle physics, reactor physics and dynamics, thermal hydraulics and coolants, risk analysis (including probabilistic risk assessments), safeguards, safety, and security (business security and fire safety), severe accidents.

As for other task forces of WP1, the data collected as well as the analysis of the responses were complemented by a literature review (survey reports, professional body websites, official documents and statistical information, IAEA Research Reactor Database (RRDB)). It should be noted that some of the data are quite old (2015).

3.3 Key outputs of TF 1.2

In December 2022, an HR survey email was sent to 132 selected organizations (waste management, R&D, technical bodies and safety authorities and some universities). The data collected through the survey was during a relatively short period due to project schedule constraints (from December 2022 until March 2023). **Only 30 responses were received (response rate 22.7%, relatively low)**. All survey responses are held in strict confidence. Faced with the low response rate (waste management organizations, safety organizations in particular), extrapolations between countries could also be used.

3.3.1 Quantitative outputs

Based on the survey results and literature study, the total workforce (direct + indirect jobs) for the EU27 + UK in nuclear R&D, regulation, and decommission and waste management is estimated over 100,000 jobs. Indirect jobs supported through the supply chains are assumed to represent roughly half of this total number.

These sectors will require over 30,000 additional jobs on the period covered by the study to compensate for retirements. The demand for clean energy and the increased range of non-power applications is likely to ensure that the nuclear sector as whole will continue to evolve and expand the next ten years. However, such increase is likely to vary in the different nuclear subsectors, depending on national policies and programmes. This is the reason why we have assumed in our simplified modelling (see Chapter 5) increases of workforce needs in this sector to cope with our 10% growth hypothesis.

3.3.1.1. Nuclear Research organizations

The order of magnitude of workforce in Nuclear R&D (including research reactors) amounts to 20,000 direct jobs. The number of employees in research and development institutions among the six 6 organizations in this category who responded to the survey is in the range of 500-999.

3.3.1.2. Safety organizations

The nuclear regulatory sector (safety and security) represents around 5,000 direct jobs according to our study. The performed survey provides limited information on staffing of safety organizations in EU27+UK (essentially national regulatory authorities for nuclear safety, security, radiation protection). The information was supplemented with data available from annual reports of the respective organizations.

The number of employees working for the regulatory authorities is in the range of 100-499 employees. The number of employees working in the organizations restricted to the role of TSO is also in the range of 100-499 employees. The total number of employees for the 16 organizations for which recent staffing information is available is just above 4,000.

3.3.1.3. Waste Management organizations

Nuclear decommissioning and waste management sectors represents 25,000 direct jobs according to our study. The number of employees working in the waste management and decommissioning organizations is in the range of 100-499 (23 public and/or private WMOs operating in 23 EU27+UK perimeter).

It should be emphasized that the number of people employed in the organizations strictly depends on the volume of radioactive waste, including those produced from decommissioning activities.

3.3.2 Qualitative outputs

The long-term perspectives related to the decarbonization of the energy sector (including nuclear fusion and the ITER project, not considered in this work), should ensure that the nuclear sector continues to develop over the next ten years and beyond. This increase in HR needs is likely to vary across European countries and across nuclear sub-sectors, depending on national policies and programmes, public health policies, and existing nuclear capacities. The survey results revealed diverse opinions about the most in-demand nuclear jobs over the next decade. However, we can identify the five main disciplines most often cited in the perimeter of TF 1.2:

- Dismantling and waste management,
- Radiation protection
- Nuclear engineering,
- Physics (nuclear),
- Medical applications (see TF 1.3).

The afore mentioned disciplines are generally expected to be high in demand as Europe continues to tackle its energy needs, public health policies, nuclear safety, and waste management challenges.

More precisely:

- Given the technical complexity and critical nature of **nuclear R&D**, it requires a highly educated staff in a wide range of disciplines, e.g., nuclear engineering, materials science, (nuclear) physics, (nuclear) chemistry, advanced reactor technologies, health physics and radiation protection, environmental science, computer science and engineering, mathematics, and statistics.
- **Nuclear regulation** encompasses a variety of disciplines to ensure the safe and responsible operation of nuclear facilities. some of the main disciplines required by nuclear regulations are nuclear engineering, radiological protection, health physics, environmental science, nuclear safety, legal and regulatory compliance, risk assessment and management.
- Some of the main discipline required in **nuclear decommissioning and waste management** are nuclear engineering, radiation protection, environmental science, and materials science. Besides these scientific disciplines, this sub-sector will also need project managers with experience in large projects and logistics, transport, handling and lifting.

Professions that are not directly related to nuclear technical jobs were not listed directly in the survey table and were classified as 'other'. Among responding organizations to the survey, total number of experts in those fields of activity appeared to be high (1,591). Most frequently mentioned professions are personnel who are responsible for the following type of tasks:

- General administration
 - Management
 - Document management (to be considered in connexion with an "Integrated Management System" as described in IAEA recommendations)
 - Finance
 - Legal duties/regulations ("compliance")
- Human resources
 - Training
 - Medical
- Technical tasks
 - Emergency preparedness response
 - Cybersecurity

The participating organizations were asked to estimate the percentage of the change in their organization's staff number in ten-years' time, starting from today's numbers. Through 30 responses (not all of them hire personnel listed in the survey), it is reported that **most of the participants believe that in ten years their staff will either increase or the staff number will remain the same. Only in one case, the predicted growth in employment will be higher than 10%**, with the organization indicating that ten years from now the increase in employment will be for skills in risk analysis.

4. Task Force 1.3 HR requirements in non-energy applications

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4.1 Non-energy applications context and challenges

The objectives of TF1.3 were to assess labour requirements for various non-energy applications using ionizing radiation. There are a variety of non-power applications using radioactive elements or radiation rays. The **most important is the use of radioisotopes for medical applications** that include both therapy (e.g., internal or external radiotherapy) and diagnostics (e.g., imaging). Other non-energy applications considered in the scope of the study include the environment and space sectors.

Radionuclide therapies are expected to play an increasing role in nuclear medicine. Radiotherapeutics represented 20% of the global nuclear medicine market in 2021, which amounts to over USD 6 billion growing by over 10% from 2020. Radiotherapeutics are expected to reach near 70% of market share by 2031. Over 150 companies are currently developing one or more radio-diagnostic or

radiotherapeutic products from their own pipeline. Several new radiotherapeutics with strong revenue potential are expected to reach the market before 2027 (estimated a +17% per year increase from 2022 to 2027). In terms of HR, an impact is expected in the recruitment of medical physicists / radiopharmacists / radiochemists.

In the environment and space sectors, it could be foreseen from the beginning of the study that such specific application areas will exhibit low numbers of nuclear staffing, since they are largely dedicated to some specific projects, with limited needs for human resources compared to the medical field.

The use of environmental tracers and isotopic hydrology techniques help to characterize groundwater and surface water resources, recharge times, processes, etc., becoming a useful tool to counteract environmental damage due to climate change. The use of nuclear technologies in the field of hydrology has helped to improve the management of water resources in all countries of the world. Hydrologists use radioisotope analyses to characterize the presence of pollutants moving through groundwater and to assess the level of vulnerability of aquifers. For any new development, agricultural, industrial, or human settlement, a sustainable supply of clean water is essential. Due to the scarcity of drinking surface water (also due to human pollution), groundwater is the largest source of fresh water, constituting 30% of the world's total. There are about 60 countries, developed and developing, that have used isotope techniques to survey their water resources in collaboration with the IAEA.

The use of radioisotope tracers is also used in food traceability, above all to evaluate the rate of possible pollutants present. Some radioisotopes harmful to the environment and to human health, following a nuclear accident, remain in the environment for a long time and if not monitored can cause serious damage. For this reason, the food is also monitored and controlled from a radiological point of view, using isotopic techniques such as gamma spectrometry. Other radioisotopes are naturally present in the environment, such as Rn-222 for example, which however must be continuously monitored using alpha radiometry isotopic techniques.

In the space sector, nuclear applications might further develop in the near future. Fifty years after the last Apollo mission in 1972, the exploration of space has returned to the centre of attention. Today, many countries are interested in missions to the moon and beyond. The establishment of human outposts on planetary surfaces, and the utilization of *in situ* resources, require the production of large amounts of electrical power. China and NASA are planning to build a fission surface power system on the moon by 2028 and by 2026, respectively. NASA has selected Westinghouse Electric Company to provide an initial design concept for a fission surface power system that could be ready to launch to the moon by the end of the decade. Westinghouse is partnered with Aerojet Rocketdyne. Belgium's Tractebel has been recently selected by the European Space Agency (ESA) to head the consortium of Pulsar, a project aimed to develop nuclear technology to power space missions. In this context, in September 2022, the European Nuclear Society High Scientific Council published its position paper titled "Nuclear Energy for Space Exploration" that highlights the fundamental contribution that nuclear energy has made to space exploration, and to highlight the need to develop new space nuclear systems to meet the future challenges of space exploration.

All these non-energy applications require specific skills and certain generic nuclear skills such as, for example, radiation protection and the handling of radioactive materials. Interactions with TF 1.2 have been developed on these aspects.

4.2 Methodology for TF 1.3 study

Within the field of medical physics, the survey used to obtain the medical physicist data referred to in this report consisted of assessing the workforce of different professionals using ionizing radiation. The number of medical physicists mentioned in this report concerns those practicing in all relevant medical specialities including nuclear medicine (medical physicists), diagnostic radiology (medical personnel including radiologists, radiographers/technologists), radiotherapy (oncologists) and radiation protection. All subspecialties were included and not accounted for separately.

The previously carried out surveys used to recover the information on the workforce corresponding to radiopharmacists / radiochemists and any relationships with the medical physics profession in terms of numbers, have concerned exclusively the field of nuclear medicine. As such they cannot be directly extrapolated using the number of medical physicists practicing in other medical fields (diagnostic radiology, radiotherapy, radiation protection).

One should also consider that the fraction of medical physicists practicing within the field of nuclear medicine relative to the whole medical physics profession are highly variable depending on each of the EU27+UK countries.

Data collection through two specific surveys was used:

- The first one was carried out by EFOMP at the end of 2022 on behalf of other European projects concerned by Medical Physics Expert workforce issues at the EU27 level. This survey provided data on the status of the Medical Physics Expert professionals and the required level of competences.
- The second survey was the one performed in the framework of TF1.2 of the present ENEN2+ project. Although a specific survey on Human Resources (HR) in Radio-pharmacy/ Radiochemistry was not launched in the framework of TF1.3, some data on the radiochemistry workforce could be obtained from the more general ENEN2+ survey in the framework of TF1.2. A few questions within this survey concerned the needs of research centres in terms of radiochemists to produce isotopes that may be used for medical applications. Only one organization producing medical radionuclides replied.

These data were exploited and confronted to the data from the literature review and secondary data sources. Unfortunately, previous data on HR in radio-pharmacy / radiochemistry in Europe are scarce and do not exactly fit with the perimeter of ENEN2+ study. We could nevertheless base the literature review on:

- Reports drawn up by international organizations (public and private):
 - A survey from the IAEA (available online: IAEA statistics on the Nuclear Medicine workforce including “Eastern Europe and Northern Asia”). IAEA data were obtained based on the “International Research Integration System (IRIS)”, which is an online data collection platform launched in 2020 by the IAEA. The data were provided on a voluntary basis and were focused on low- and middle-income countries, from Africa, Asia, Eastern Europe, and Northern Asia, Latin America & Caribbean, and Middle East. The survey included a total of 1427 institutions. No data from high-income countries, namely from Western Europe, was included at this stage.
 - EU project reports containing relevant human resources information for the targeted occupational categories and associated applications.

- Reports from national authorities or professional associations in specific countries, specifically one report from the British Nuclear Medicine Society (published in the journal Nuclear Medicine Communications)
- Although not focusing directly on data for the nuclear medicine workforce, recent surveys/reports helpful for forecasting the impact of nuclear medicine modalities in the years to come:
 - The “Questionnaire on industrial and clinical key players and needs” issued by the PRISMAP project (European medical isotope programme: Production of high purity isotopes by mass separation, INFRAIA funded) aiming to federate a consortium of the key European intense neutron sources, isotope mass separation facilities and high-power accelerators and cyclotrons, with leading biomedical research institutes and hospitals active in the translation of the emerging radionuclides into medical diagnosis and treatment. Two of the ENEN2plus partners (NCBJ/Poland and IST/Portugal) are also partners of the PRISMAP project.
 - The Nuclear Medicine Report & Directory, Edition 2022 by MEDraysintell.

Applications in the space sector and the environment have been studied only by this literature review, as they involve activities limited to a very small number of projects and competent bodies, often funded by specific R&D programmes of international organizations (European Space Agency in particular).

4.3 Key-outputs of TF 1.3

4.3.1 Medical Physics

For the medical sector, the EFOMP survey covered education and training, workforce availability, workforce planning. According to the results of this survey, **there are a total of nearly 10,000 medical physicists in Europe** (precisely 9809) representing 3.9% of the overall workforce within the medical applications field using ionizing radiation (including medical doctors, radiographers, and radiology technologists). **The average is 21 per 1,000,000 inhabitants**, with great variability from 4 to 43 depending on the country. These numbers concern all different medical specialties within medical physics (nuclear medicine, radiology, radiotherapy).

In terms of demographics, about 7% of the specialists concerned will retire in the next 5 years and 22% are over 51 years old. This concern is consistent with what has been observed in TF1.2 study regarding the ageing pyramid of senior experts. The increasing interest of radionuclide therapies requiring dosimetry studies and the rapid introduction of artificial intelligence software in clinical practice will have a positive impact in the required number of MPEs.

The duration of specialized training programmes varies considerably from 1 to 7 years depending on the country with an average of 3.2 years. 25% to 75% of this period (depending on each EU country) covers the practical component in an appropriate clinical setting. Similar disparities can be observed for radiation protection training, which ranges from zero to more than 52 weeks.

Different guidelines/core curricula exist for medical physics training considering the different areas of activity using ionizing radiation, namely nuclear medicine, radiology, and radiotherapy. Some of them are very recent, some are dating from over a decade ago. However, EFOMP in collaboration with the relevant European medical associations have already revised the Medical Physics Expert (MPE) core curriculum for radiotherapy (with ESTRO) and are currently revising the MPE core curriculum for nuclear medicine (with EANM). The most important guidelines are:

- The minimum entry level to a medical physics training programme to become an MPE is a BSc degree predominantly in physics (in certain cases, alternative degrees including BSc in engineering sciences is considered as appropriate)
- A postgraduate degree (MSc in medical physics / radiation physics) is included as a requirement amongst the most recently revised core curriculum guidelines issued for radiotherapy medical physics experts. This is also the case in the IAEA guidelines for medical physics training in nuclear medicine.
- The duration of the training recommendations is on average 4 years, including a 2-year minimum clinical training practice (50% partition of the training theoretical / practical) within a clinical environment / healthcare facility accredited by a national competent authority. This partition may vary from 25% to 75% for the practical component depending on the EU country.
- Most guidelines recommend a 10-15% of the total ECTS dedicated to radiation protection. The requirements for certification in radiation protection varies largely depending on the EU country.
- Following training and qualification as an MPE, continuous education for professional development is considered mandatory.

4.3.2 Radiopharmacists and radiochemists

According to existing literature, **the number of radiopharmacists and radiochemists is between 3.5% and 5.2% of the total nuclear medicine workforce** (including medical physicists, nuclear medicine physicians, radiologists/technologists, nurses), leading to around 1,000 jobs maximal estimation.

There were **ten answers to the ENEN2+ survey** from European organizations, including regulatory authorities, R&D institutes, and technical safety organisations (TSO) which were considered as relevant to TF1.3. **Data showed that employees involved in radiochemistry represent 2.5% of nuclear experts involved in the operation of research reactors.** Less than 1% of the utilities' workforce staff are radiochemistry experts and ~2% in safety authorities and technical support organizations.

Most respondents estimate that in 10 years, their radiochemistry staff will have increased by less than 10%. At the same time, survey results show through analysis of open-end-questions that organizations already have problems finding skilled workers specialized in radiochemistry.

Radionuclide therapies increasing role in nuclear medicine might still increase this tension in the recruitment of medical physicists / radiopharmacists / radiochemists among the various entities involved in the field (companies, hospitals, research centres, etc.). This issue needs to be addressed to support the expected increase in radiopharmaceutical production at existing and new nuclear facilities. This is the reason why we have assumed in our simplified modelling (see Chapter 5) a significant increase in growth of workforce needs for radiopharmacists / radiochemists in the period to come, both for direct and indirect jobs, compared to the number in 2023 estimated at around 1,000 (direct jobs).

4.3.3 Nuclear applications in the environment sector

In the environmental field, nuclear technologies are not applied on a daily basis by all research centres involved in environmental R&D programmes, but by a small number of specific centres for monitoring environmental radioactivity, whose **laboratory staff must combine multidisciplinary skills in connection with environmental sciences** (chemistry: analysis of radioactive contaminants, radioactivity in food chemistry, chemistry of industrial or hospital wastewater, etc.; geosciences:

pollution of sediments, soil or water, etc.; meteorology: microphysical processes occurring high in clouds, numerical simulations, etc.; climatology).

Based on the information gathered, the key nuclear technologies needed for environmental applications are:

- alpha spectrometry for the characterization of alpha emitters (e.g., Rn-122) in the environment or emitted by building materials
- beta spectrometry for the determination of tritium or chlorine-36 in water (aquifer dating); for the determination of ¹⁴C for archaeological data and paleoclimatology
- gamma spectrometry for the determination of emitters in the environment related to nuclear accidents or illicit nuclear tests (e.g., xenon-133, cesium-137)

4.3.4 Nuclear applications in the space sector

Based on the information gathered, the key nuclear technologies needed for space applications are:

- Propulsion: nuclear thermal (NTP), nuclear electric (CIP)
- Power generation: static systems (thermoelectric and thermionic), dynamic systems (Rankine cycle, Brayton cycle, Stirling cycle)
- Radiation detectors

The expertise required includes nuclear engineering, reactor physics, nuclear materials and chemistry, reactor systems and engineering, thermal hydraulics, safety, and radiation protection. These expertise areas are already present in the community involved in the nuclear field. The changing human resource requirements for nuclear space applications are in consequence closely linked to market demand in all segments of energy-related nuclear applications and could therefore follow the recommendations of the TF1.1 report.

5. Summary and aggregation of key figures, simplified model within the WP1 perimeter

Based on collected data and trends shown by the three task-forces reports, we have built a simplified model leading to the summarized results illustrated in Figure 3. We have assumed roughly ten new nuclear power plants to be built in an “average” 10% growth scenario. Impact on workforce has simply been assumed to be a 10% growth for most of sub-sectors, with some modulations to describe “side effects” such as:

- Increased ratio indirect/direct jobs in the industry perimeter during construction phase for new builds
- Possible increase of needs in the regulatory sector to manage licencing of innovative nuclear reactors concepts.

The parameters of this simplified model were adjusted to describe as far as possible the results of the three TF reports. The accuracy of the results from the model can't be expected better than 10%.

Two values for the annual recruitment rate (2.0 and 2.5% per year) are used to replace retirement in the industry (TF1.1 perimeter) in order to exhibit the high sensitivity of final results with respect to this parameter, due to the fact that the largest workforce in terms of numbers is in industry (TF1.1). The value of this parameter was set to a higher value (between 3.0 and 3.5% per year) in the perimeters of TF 1.2 and 1.3 considering that these sectors of the workforce have a bigger share of senior experts,

than in industry. More detailed demographic studies should be conducted to consolidate these hypotheses.

It should be underlined that we did not consider any effect on workforce needs resulting from improvements of productivity in the industrial sector. Such improvements will for sure appear based on experience feedback from operation as well as from construction of new reactors and should be analysed in a dedicated study.

According to our research results:

- In the WP1 perimeter, it is projected that between 196,000 jobs (111,000 for retirement compensation using a retirement rate of 2.0% per year, near 77,000 of those being direct jobs) and 215,000 jobs (130,000 for retirement compensation using a retirement rate of 2.5% per year, near 86,000 of those being direct jobs) will need to be recruited by 2035 in the EU27+UK. In addition, 85,000 jobs will need to be recruited for growth in our 10% growth hypothesis, 24,000 of those being direct jobs, 61,000 indirect. These figures underline that high priority should be given to preparing and securing workforce in the supply chain, especially for coping with a growth hypothesis.
- The perimeter of Task Force 1.1 (industry for nuclear energy application) represents the largest contribution to the total nuclear sector workforce in 2023 (380,000 out of 500,000 total direct and indirect jobs), as well as for the 2035 forecast.
- In nuclear research and development, regulation and decommission and waste management (TF1.2 perimeter) the 2023 workforce is estimated around 50,000 jobs at least. Indirect jobs supported through the supply chains are assumed to be similar in number at least, bringing the total to over 100,000 jobs. Over 30,000 additional direct jobs on the period covered by the study just to compensate for retirements.
- In the TF1.3 perimeter, we introduced a relatively high value of growth as a hypothesis for radiochemists / radiopharmacists to describe the increasing role of radionuclide therapies in nuclear medicine. Limited numbers of staff for environment and space applications were introduced, which are in the error margin of our simplified approach.

Task-Force	Sub-sector	2023			Needed recruitments horizon 2035							Total
		Workforce			Retirement compensation			For growth				
		Direct jobs	Indirect jobs (supply chain)	Total Nuclear sector	Direct jobs	Indirect jobs (supply chain)	Sub-total	Growth rate Hypothesis	Direct jobs	Indirect jobs (supply chain)	Sub-total	
TF1.1	Industry (Utilities)	80	80	160	20	20	40	0,10	8,0	8,0	16,0	56,0
	Industry (Fuel)	50	60	110	13	15	28	0,10	5,0	12,0	17,0	44,5
	Industry (Engineering)	30	51	81	8	13	20	0,10	3,0	25,5	28,5	48,8
	Industry (Transport & others)	10	19	29	3	5	7	0,10	1,0	9,5	10,5	17,8
TF1.1 perimeter		170	210	380	43	53	95		17	55	72	167
TF1.2	R&D (incl Research reactors)	20	15	35	6	3	9	0,10	2,0	1,5	3,5	12,5
	Safety (Regulators+TSOs)	5	5	10	1,5	1,5	3	0,15	0,8	0,5	1,3	4,3
	Waste & Decommissioning	25	35	60	7,5	10,5	18	0,10	2,5	3,5	6,0	24,0
TF1.2 perimeter		50	55	105	15	15	30		5	6	11	41
TF1.3	Medical Physicists	10	2	12	4	0,6	4,6	0,08	0,75	0,15	0,90	5,5
	Radio pharma & Radio chem	1	1	2	0,35	0,25	0,6	0,50	0,50	0,50	1,00	1,6
	Space & Environment	0,3	0,3	0,6	0,09	0,06	0,15	0,05	0,02	0,02	0,03	0,2
TF1.3 perimeter		11	3	15	4	1	5		1	1	2	7
Total WP1 perimeter		231	268	500	62	68	130		24	61	85	215

Hypothesis 2.5% per year recruitments for retirement compensation

Task-Force	Sub-sector	2023			Needed recruitments horizon 2035							
		Workforce			Retirement compensation			For growth			Total	
		Direct jobs	Indirect jobs (supply chain)	Total Nuclear sector	Direct jobs	Indirect jobs (supply chain)	Sub-total	Growth rate Hypothesis	Direct jobs	Indirect jobs (supply chain)		Sub- total
TF1.1	Industry (Utilities)	80	80	160	16	16	32	0,10	8,0	8,0	16,0	48,0
	Industry (Fuel)	50	60	110	10	12	22	0,10	5,0	12,0	17,0	39,0
	Industry (Engineering)	30	51	81	6	10	16	0,10	3,0	25,5	28,5	44,7
	Industry (Transport & others)	10	19	29	2	4	6	0,10	1,0	9,5	10,5	16,3
TF1.1 perimeter		170	210	380	34	42	76		17,0	55,0	72,0	148
TF1.2	R&D (incl Research reactors)	20	15	35	6	3	9	0,10	2,0	1,5	3,5	12,5
	Safety (Regulators+TSOs)	5	5	10	1,5	1,5	3	0,15	0,8	0,5	1,3	4,3
	Waste & Decommissioning	25	35	60	7,5	10,5	18	0,10	2,5	3,5	6,0	24,0
TF1.2 perimeter		50	55	105	15	15	30		5,3	5,5	10,8	41
TF1.3	Medical Physicists	10	2	12	4	0,6	4,6	0,08	0,75	0,15	0,90	5,5
	Radio pharma & Radio chem	1	1	2	0,35	0,25	0,6	0,50	0,50	0,50	1,00	1,6
	Space & Environment	0,3	0,3	0,6	0,09	0,06	0,15	0,05	0,02	0,02	0,03	0,2
TF1.3 perimeter		11	3	15	4	1	5		1	1	2	7
Total WP1 perimeter		231	268	500	53	58	111		24	61	85	196

Hypothesis 2.0% per year recruitments for retirement compensation

Figure 3: EU27+UK estimated nuclear workforce distribution in nuclear sub-sectors, estimated recruitments in 2035 horizon
(in thousands of jobs, based on outputs from all three task forces and simplified modelling)

6. Discussion and pain points

6.1 Limitations due to data collection and data quality

A shared observation from the three Task-Forces studies is that **it is very difficult to obtain accurate data on the nuclear workforce through Europe-wide surveys**. The limited response rate after the survey implemented at the very beginning of the study by TF 1.1 and 1.2 can be a cause for concern as it may not provide a representative sample of the entire nuclear sector. Literature review provided valuable complementary data; however, it was limited to online information and available databases, sometimes somewhat out of date.

One possible reason for this limited response rate from the industrial segment of our study could be the sensitivity of the data being collected. HR numbers, particularly related to workforce composition and skill requirements, are often considered confidential and proprietary information. Organizations may be hesitant to share this information due to concerns about competitive advantage or other factors, although it was clearly stated that responses to the survey shall be anonymized (a disclaimer in the survey sent to all potential contributors stated that *“the responses to the survey will be kept anonymous and the individual data collected will be kept confidential”*).

In the R&D part of the study's perimeter, access to accurate data appeared also to be difficult for various reasons:

- Universities which potentially play a significant role could only be partially addressed through the survey methodology.
- For Research reactors, evaluating HR and staff faces another difficulty: in some cases, the number of people involved in research reactors operation might be different from staff of the organization responsible for it. Research teams invited might come from other organizations, including universities, for specific research programmes.
- Despite its major contribution in EU strategy, the ITER project and more generally fusion programmes were not taken in consideration here.

Consequently, the findings and conclusions drawn from data collected in this study should be considered as rough estimates of HR needs and interpreted with caution. Further study would be highly desirable.

6.2 Consistency of results: simplified benchmarking approach

Fully aware of the above-mentioned limitations, we have deemed necessary to cross check at least orders of magnitudes, consistency, and trends of our results, including those of our simplified modelling.

We took advantage for this purpose of the recent release of France's Match Programme. Both the Match Programme and the ENEN2+ project have as time horizon 2035 (or "10 years from now", sensitivity of our results to one year more or less in the horizon being for sure included in the uncertainty margins).

The Match Programme chose to tally the workforce in FTE (Full Time Equivalent) whereas the ENEN2plus considers "jobs". Consequently, needs in terms of E&T issued from our approach might be underestimated compared with the Match results: if more than one individual is employed to fulfil one task, more than one individual will have to be properly trained. Obviously, for future studies a common approach should be agreed to compare and compile at EU level data from studies conducted in different EU Member States.

Let's consider as benchmarking reference that the French nuclear fleet represents roughly half (56/109) of the EU27+UK fleet. We have compared some results of the study with those from the Match Programme used as a benchmark. Even if the Match analysis conducted by the Gifen was mainly focusing on industry, we assumed it can be relevant to compare with the perimeter of WP1. Of course, countries specificities and a wide range of scenarios must be kept in mind in such a benchmarking approach.

The Match Programme indicates that the civil nuclear workforce in France is estimated at 220,000 jobs of which 125,000 are direct jobs. For EU27+UK perimeter, corresponding figures are 500,000 of which 230,000 directs jobs. Ratios are consistent with our rule of thumb "benchmark reference" (56/109).

These figures also help to confirm our hypothesis of doubling workforce size when considering contribution of the nuclear supply chain, provided we consider that indirect jobs are in majority in the supply chain (ratio indirect/direct for 2023 = 1.16 from our modelling approach).

Regarding trends for the future, the Match Programme predicts a 25% increase in workload over the next ten years, requiring approximately 60,000 new full-time equivalent (FTE) hires in France, the turnover representing 30,000 for retirements or movements to other sectors, and 30,000 for growth. Most of this growth is expected in the supply chain in France related to new build (6 EPR2).

Our corresponding estimations at EU27+UK level are:

- New recruitments for retirement compensation:
 - Direct jobs: between 53,000 and 62,000 (among which between 34,000 and 43,000 in the perimeter of TF1.1)
 - Indirect jobs (assuming this represents roughly the supply chain sector): between 58,000 and 68,000 (among which between 42,000 and 53,000 in the perimeter of TF1.1)
- Indirect new recruitments for new builds: 61,000 (among which 55,000 in the perimeter of TF1.1)

This simplified benchmark shows that:

- Total direct + indirect new recruitments for retirement compensation might have been slightly overestimated in our study ($130,000/500,000 = 26\%$ with the hypothesis of 2.5% per year recruitments for retirement compensation in the TF1.1 perimeter). In further demographic studies, compensation for retirement should be distinguished from compensation for moves during careers to other non-nuclear industrial employers. The pressure for workers to move to other non-nuclear industrial employers (attractiveness of the renewables sector *inter alia*) might be stronger at the EU level than it is in France in 2023. Future improvements in industrial processes might also lead to reduce needs for replacement of retirements.
- The ratio of increase of total workforce is much higher in our results at the EU27+UK level ($\sim 196,000/500,000 = 39\%$ even with the lower value of 2.0% per year for retirement compensation in the TF1.1 perimeter) than for the French study ($60,000/220,000 = 27\%$) which might be interpreted as the consequence of our hypothesis of new EU countries embarking in a new nuclear programme.
- Recruitment of indirect jobs (i.e., in the “supply chain” in our hypothesis) should be considered as top priority when considering new builds challenges (55,000 indirect jobs vs 17,000 direct in the perimeter of TF 1.1), which correspond to the French Match Programme comment on workforce growth for the EPR2 programme.

Nevertheless, it should be emphasized that disparities are significant at EU27+UK level: Spain foresees an overall decrease in staff of 20%. In light of this, **it is essential for companies and policymakers to collaborate and formulate strategies to address potential labour market imbalances in different regions.**

Regarding safety organizations with the same simplified benchmarking approach, total staff for the regulatory authority and technical safety organization in France amounts to roughly 2,300 (ASN: 516 (source annual report 2022), IRSN: 1816 (source key figures 2021), among which 438 FTE dedicated to research) which gives the rule of thumb ratio $2300/59 = 39$ staff/reactor. This figure is of course non-linear: the larger the fleet is (as it is the case in France), the lower the figure will be, taking advantage of mutualization of expertise and of administrative parts of the missions. One can consider that the staffing of RA+TSO should range from 40 to 80/reactor typically. Applied to EU27+UK perimeter, this would lead to between 4,300 and 8,700 staff for existing fleet, and an increase of 400 and 800 to manage our growth hypothesis. Our estimations are 5,000 (direct jobs) for current situation and 750 for new recruitments in relation with growth, therefore they appear to be consistent.

6.3 Discussion of qualitative results

6.3.1 Direct and indirect jobs

In the 2023 situation, ratio between direct and indirect jobs in the perimeter of TF1.1 and TF1.2 are consistent with order of magnitude 50/50: one direct job for one indirect, and we considered in a first approach that these indirect jobs numbers are roughly an estimation of the supply chain workforce.

It should be noticed that among industrial responders to the survey, design, engineering, manufacturing, and maintenance segment of activity is significantly the more represented (42%). This might be an indication of the fact that companies in this segment are more open to share their data, and perhaps more motivated to contribute to the type of study we propose in the present report.

While direct jobs can be estimated with rather high accuracy, the number of indirect jobs has a higher margin of uncertainty due, among other factors, to variability in job roles within supply chains. Recognizing this uncertainty is crucial for understanding of the industry's workforce dynamics, as we have underlined that workforce needs in the supply chain should be considered as top priority. A strong local supply chain (at present 54% of direct + indirect total 500,000 jobs, this ratio might be even increased with workforce demand for new builds) in the EU27+UK offers high-quality jobs located in Europe. This issue of future jobs localization should deserve specific attention from policymakers, in the context of globalized international market of nuclear industry with renewed ambitions from US industrial players and significant newcomers on the supply side (South Korea, China, etc.).

Regarding induced jobs, we have seen that in EU27+UK it almost doubles the total number of direct + indirect jobs of the sector. Even if we have not in this report gone to further analysis of this category of induced jobs, we can notice that:

- They are probably for a large part associated to new build works, due to high concentration of non-permanent workers (several thousands) on site during the construction phase,
- Therefore, they will be for a large part located in areas where such works will be conducted, which may explain efforts of local policymakers to attract new builds projects in areas they are responsible for.

6.3.2 HR skills are difficult to categorize

A possible explanation of the observed general trend towards the "other" category in responses to the survey is the ability (and wish) of industrial companies to train their new personnel in-house through VET (Vocational Education and Training), considering that general initial skills are sufficient. This interpretation, if confirmed, should be considered as a positive result of our study.

Several other explanations, perhaps less positive, of the same trend might be considered: difficulty in anticipating jobs and roles and how they fit with initial skills to fulfil operational demands, lack of visibility on future activity related to programmes which are themselves submitted to uncertainties, evolution of nuclear technologies towards more intense integration of generic non-nuclear technologies (digital tools especially), etc.

It can be also an indication of the fact that the jobs classification used in the survey was too general and does not fit with on the grassroots industrial reality. Questioning the methodology itself used in the present study should be explored before undertaking any new studies.

Regarding jobs / skills classification, it should be underlined that the higher the job is in the competences pyramid, the narrower is its definition. On the top of the pyramid, the skills of experts even depend on the specific technology of the plant operated and can only be acquired by on-the-job training with compulsory major input from industrial companies (either design or operator) rather than from academic institutions. Here is perhaps one of the paradoxes in outputs of the study: the higher the expertise required, hence the more difficult it is to find on the labour market, the longer it is to train, the less the academic training can fit with demand. Nevertheless, simultaneously, rapid action at national level, especially for the countries implementing a nuclear programme is necessary. Here might be one of the identified bottlenecks of HR needs for the future.

Fortunately, the largest part of future HR needs in number, for industry, do not fall in this “experts” category, as demonstrated by the trend to “other” type of skills in responses to the survey.

6.3.3 HR needs are strongly time dependent

The scope of competences changes over the life cycle of the nuclear facilities, clearly inducing a strong impact on the anticipation of the number and types of competences needed overtime. For countries involved in new builds project, some milestones will introduce changes in the number and type of competences needed such as:

- regulatory framework set up, investment decision,
- owner/operator set up,
- first concrete, first fuel loading, first connection to the grid,
- start of decommissioning, dismantling phase, etc.

The case of the plant owner and/or operator is a typical and critical example because it must:

- manage construction phase, engineering, on site works control, civil works competences will be critical and will induce peaks in terms of number of workers,
- ensure availability of staff for safe and secure operation and maintenance of the nuclear plant during its whole lifetime (60 years or more), shift managers need a very specific and long-lasting training before being certified. Job mobility, retirements, and eventually new builds to come simultaneously must be considered in HR long-term planning,
- acquire in-depth knowledge of the plant to conduct decommissioning and dismantling phases, therefore relying mainly on owner/operator staff in charge of the plant during its operation. For dismantling, specialized companies might bring their own know-how, therefore introducing new needs in competences.

Whereas the trained workforce should be available at the right time, it is also essential that the trained workforce is not ready too early. Experience has demonstrated that many trained people, when they have had no opportunity to work for the nuclear sector because of delays, moved to other activities and were then “lost” for the nuclear value chain.

6.3.4 Ratio of new recruitments to compensate for retirements

We introduced for simplified modelling purposes ratio of new recruitments to compensate retirements with variations according to activity sector (between 0.20 and 0.35). Sensitivity to this parameter, especially in the perimeter of industry (TF 1.1) has been clearly illustrated in Chapter 5.

Data collected in the study (and used to fit parameters of our simplified model) shows that ratio of new recruitments to compensate retirements is much higher in the perimeter of TF 1.2

(30,000/105,000 = 29%) compared with TF 1.1 results (according to the hypothesis: 76,000/380,000 = 20%, 95,000/380,000 = 25%). A demographic issue has also been identified in the perimeter of TF1.3 for medical physicists.

Even if we consider these results cautiously, the trend can be interpreted when considering that staff in organizations analysed in TF1.2 and in TF 1.3 includes probably more “senior experts” (EQF level 7-8), therefore is probably older in average. This should be analysed more in details in further studies through detailed demographic data analysis.

It seems important when looking at these data, limited to nuclear experts, to remind that experience has shown that the technicians and semi-skilled workers form a very large portion of the needed workforce, for which E&T must also be addressed cautiously. The survey did not include information about technicians; therefore, the recommendations cannot address any gaps in this area and would need to be further investigated.

In the perimeter of TF1.2, organizations were asked why it is so difficult today to recruit qualified nuclear experts. Among respondents, the most common reasons given were the:

- transfer to the private sector with better wages;
- reduced attractiveness of R&D salaries compared to industry;
- limited possibility to recruit foreign experts due to language barrier;
- decrease in the number of students in universities relative to market needs;
- the fact that nuclear specializations require more time to be job ready.

7. Recommendations

7.1 General recommendations

HR is a time dependent concern. As a general summary of the goal to be reached, it is necessary for the EU27+UK nuclear organizations to look at the **mobility of nuclear employees to meet the need to have the right resources in the right place at the right time**. Let's strongly underline that **the quantification process for HR needs should be considered and managed as an iterative process, as well as the definition of HR development solutions, taking into account demographic parameters**.

It appears crucial to prioritise and focus efforts for any categories of professionals and for any category of organizations in the nuclear sector on the following three simple principles, however not so easy to implement for managers in charge:

- **Attracting new talent:** Implement targeted recruitment campaigns and initiatives to attract young professionals, students, and individuals with diverse backgrounds to the nuclear sector. Highlight career opportunities and advancements in technology. Collaborate with educational institutions to promote nuclear-related programmes and create awareness among students about the benefits of pursuing a career in the nuclear field.
- **Developing current talent:** Invest in the continuous development and upskilling of the existing nuclear workforce. Provide training programmes, workshops, and professional development opportunities to enhance their knowledge, competencies, and adaptability to evolving technologies and industry standards. Foster a culture of lifelong learning and innovation within the sector to ensure that professionals stay at the forefront of advancements in the field.

- **Retaining skilled professionals:** Create a supportive work environment that values and rewards the contributions of nuclear professionals. Offer competitive compensation packages, opportunities for career advancement, and a healthy work-life balance. Implement retention strategies such as mentorship programmes, employee recognition, and a strong organizational culture that promotes job satisfaction, professional growth, and work-life balance.

To attract and retain skilled professionals, it is crucial to highlight the challenging and intellectually stimulating nature of the work, the potential for career growth, and the opportunity to work with cutting-edge technologies and innovative solutions. Creating a positive work environment that fosters collaboration, professional development, and work-life balance is equally important in attracting top talent.

Attract the younger generation to the nuclear sector appears to be one of the top challenges. It will be necessary in this perspective to increase flexibility in career development and address the mobility of nuclear employees, whether within each company or institution, from one country to another, and from one nuclear activity to another (from research to industry, from safety to decommissioning, etc.).

It should be strongly recalled here that **common terminology, unambiguous qualitative and quantitative criteria for mapping jobs and skills, as well as common rules for certification or qualification issued to companies or their employees, would facilitate this mobility** (for example, the European ECVET credit system for vocational education and training was replaced by a Council Recommendation of November 2020 on vocational education and training (VET), "for sustainable competitiveness, social equity and resilience").

In addition, more **efforts need to be made to recruit women into the nuclear sector**, especially in industry. Having a diverse workforce is key to success. Bringing together more diverse views would allow a different approach to problem-solving and innovation.

7.1.1 Recommendations for Industry

To attract and retain top talent, the industry should **provide opportunities for mobility and career flexibility through economic incentives and simplified procedures**. By fostering a culture of career development and mobility, the nuclear industry can position itself as an attractive and dynamic sector.

Particular attention should be paid by industry to the loss of knowledge (mainly tacit knowledge) due to retirement and the associated knowledge transfer challenges. Particular attention should be paid to transmission of **expertise and know-how of senior employees**, with as example of practical methods to be developed mentoring initiatives, opportunities for young retirees to dedicate part of their free time to junior employees, etc.

The adoption of the concept of **lifelong learning** and the provision of additional industry-specific training programmes, workshops and seminars could improve skills in the sector. Continuing education is an essential aspect to be considered by industry, as it complements initial academic training regardless of the level of study. For vocational education and training (VET), it is recommended to continue the harmonization effort, and to follow the seven recommendations made by Cedefop to improve the quality, relevance, and effectiveness of training.

The nuclear industry should be encouraged to **invest in R&D** by allocating resources to initiatives focused on nuclear technology, safety, waste management, etc. to stimulate innovation and improve

safety in design and operation. Industry should also **increase its support for education and training**, by providing support for scholarships to students pursuing nuclear-related studies.

Moreover, decrease in the interest of the young generation for nuclear, especially in Member States where the phase-out was already declared and the need to prepare the workforce by vocational education should be considered as well. This could for example lead to develop more intensively intra-companies' careers opportunities for multi-sectorial companies, through "nuclearization" specific training programmes for employees previously experienced in other non-nuclear activities. Development of transnational cooperation programmes should be considered to address this specific issue. More generally, companies should look for more collaboration at EU level to share best practices in terms of access to talents and HR strategies.

Recognizing that a significant part of the HR needs are "nuclearized" profiles rather than nuclear experts, companies might open more widely the panel of E&T curricula they consider for new recruitments.

The present study did not consider any effect on workforce needs resulting from improvements of productivity in the industrial sector. Such improvements will for sure appear and should be analysed in a dedicated study.

7.1.2 Recommendations for E&T providers

Promotion of nuclear awareness modules in education curriculum including in vocational training (technicians, computer technology, health professionals, etc.) should begin as early as possible in the young people's education and might help make the nuclear sector more attractive. Information/awareness-raising actions could be organized at universities and engineering schools in order to identify and motivate young candidates interested in these demanding professions but with very high career development potential very early on.

The nuclear sector could benefit of a **closer collaboration between education and training providers and the industry**. This collaboration can be achieved through joint initiatives, participation in industry advisory boards, and regular dialogue with industry professionals, who can provide valuable insights into the skills and knowledge required by the nuclear sector to ensure that the educational programmes and training courses align with the industry's evolving needs.

More specifically, to promote a more effective connection between industry, research and academia, it is recommended to **establish a sustainable network** of industrial facilities and research infrastructures across Europe to deliver specific and efficient E&T programmes. Integration of a European Competence Framework between universities, public authorities and industry should be stimulated by long-term support.

To better fit with the evolving needs of the industry, education and training providers should propose more **multidisciplinary curricula**. Nuclear energy involves various aspects, including engineering, physics, chemistry, environmental sciences, policy, and economics. As it was underlined in the study of non-energy nuclear applications, connexion with space or environmental science must be developed for example. For a limited number of highly motivated students, it would be useful to organize and promote dual training curricula (Space + Nuclear, Environment + Nuclear).

A key recommendation is that these multidisciplinary curricula should **emphasize the integration of technical knowledge with a comprehensive understanding of the broader context in which the nuclear sector operates**. Soft skills, including leadership, communication, teamwork, problem-solving,

and adaptability, are crucial for professionals working in complex and high-stakes environments, and therefore for success of the nuclear industry. Wide range of soft skills, related to “soft-science” disciplines, are now part of the employees-citizens necessary background appreciated in recruitments processes: legal skills, innovation management, communication, of course, but also social and public behavior related topics, eventually controversial: stakeholders involvement in public policies decisions, NGOs, impact of social networks on innovation diffusion, information and fake news, ethic issues for engineers, science and opinions, etc.

Simultaneously, as detailed below in this report, academic organizations which deliver E&T should keep in line with international top-level science and technology, including in basic nuclear sciences. **High level R&D is fundamental for high level E&T.** The European Nuclear Education Network (ENEN) lists 53 nuclear master programmes in the EU27+UK. **Assessment of contents** of this high value E&T potential for EU is a sensitive topic knowing the legitimate autonomy of academic organizations. Nevertheless, looking for harmonization in this assessment process should be an objective to facilitate mobility among EU countries of graduated students.

Promoting and strengthening networks among EU E&T institutions, public or private, as well as among EU nuclear R&D infrastructures might be a positive move in this direction. Development of employment opportunities for EU citizens, priority given to EU companies, should be considered among criteria when EU fundings are involved in such cooperative initiatives.

E&T institutions should continue to work towards harmonization at the EU level. For Vocational Education and Training (VET), it is recommended to follow the seven recommendations put forward by Cedefop to improve the quality, relevance, and effectiveness of VET trainings. A first step would be to establish learning outcomes for VET courses.

In parallel with these mid to long-term recommendations, **rapid action at the national level, especially for countries implementing a nuclear programme, is needed.** Due to the long duration to establish appropriate expertise, the importance of the implementation plans is greater in the nuclear sector than for other sectors. Improved international cooperation is crucial to face this challenge. Networking in the field of nuclear education (open access to education in nuclear R&D facilities, summer schools, joint experimental and computer simulation courses, etc.).

7.1.3 Recommendations for policymakers

7.1.3.1 At national level

Firstly, the responsibilities of policymakers, across political party lines, are to **create stable mid to long-term confidence**, essential for attracting young talents. Transparent and well-defined national policies will provide industry stakeholders, investors, and the workforce with a clear understanding of the government's expectations. Governments should publish clear policies and plans regarding their stance on nuclear energy.

The dynamic and contextuality of the attractivity of the European nuclear sector should be deeply analysed. The diversity of contexts leads to different objectives between Member States. On the other hand, E&T remains a common key component to ensure the necessary knowledge for the operational purpose of all nuclear applications. The concern of **future jobs localization** should deserve specific attention, in the context of globalized international market of nuclear industry. An important loss of workforce in the nuclear sector may appear by migration outside of the EU into regions with a high rate of implementation of new nuclear projects. Among numerous possible influent factors, loss of attractivity of STEMs in general, increased attractivity of other technological areas for young people (AI, robotics, big data, block chains, additive manufacturing, etc.), preferences for easier jobs, etc.

In such conditions, policymakers should develop first a diagnostic, then a resilient action plan to ensure sufficient and performant workforce. **National nuclear workforce assessments (NWA) periodically updated emerge as a crucial tool to comprehensively understand current and future human resource demands, first at national level then consolidated at European level.** At present, the UK is the only country that regularly publishes a nuclear workforce assessment. **Policymakers should take the lead in promoting and facilitating NWAs,** because they impulse is necessary to succeed in such an approach which can only be effective with the active participation of all relevant stakeholders (ministries responsible for nuclear programmes, industrial organizations, regulatory authorities, technical safety bodies, research and training infrastructures, universities).

NWAs produced should be updated, ideally every year, or in the event of significant changes in national circumstances. The main steps of such NWA process are:

- Mapping of current nuclear workforce, including demographic information which need to be monitored closely and more systematically (age, years of experience, competences, gender, education level)
- Anticipating future nuclear workforce needs (can be scenario based and supported with workforce modelling tools)
- Mapping of supply of workforce (one academic discipline can supply workforce to different economic sectors, supply can also be through mobility, reskilling, and upskilling)
- Conduct gap analysis and share results with all involved stakeholders
- Develop a nuclear skills strategy addressing possible gaps, options can be introduced (self-sufficient strategy, international partnership, ...), choice in hands of policymakers
- Implement the chosen skills strategy
- Assess and review of the NWA process (at least every two years).

7.1.3.2 At EU level

The study conducted in ENEN2+ WP1 has evidenced that data collection by survey methodology provided few responses (< 30%), leading to uncertainties in the interpretation of the data. Even though the delay allowed to implement it in the present project was quite short, and might explain the limited number of received answers, the methodology based on surveys might be questioned for the future.

Among possible improvement directions, compiling the information at the EU level, and establishing European wide recommendation might be an objective, based on the national recommendations issued from national Nuclear Workforce Assessments. In addition, efforts towards harmonization of skills assessment methodologies in the EU27+UK perimeter would be welcome to facilitate future studies on nuclear workforce assessment.

The diversity of contexts (new developments, new investments, extension of operating times, phasing out for some countries) leads to different objectives between Member States. On the other hand, E&T remains a common key component to ensure the necessary knowledge for the operational purpose of the nuclear installations, radioactive waste management, decommissioning, R&D activities, etc.

This is the reason why binning results of national NWAs at the EU level, rather than keeping them only at a country-by-country level, is clearly a way to collectively minimize and mitigate risks of lack of needed HR and skills in near future. It is also a path to consolidate both the EU's low carbon energy strategy, and EU leadership to face international nuclear technologies development opportunities.

The EU JRC, involved as contributor in Task Forces 1.1 and 1.2 in the present project, might be invited to further develop efforts with EHRO-N to provide more efficient methodology guidelines in collaboration perhaps with the OECD Nuclear Energy Agency who is also interested in the subject. EHRO-N might play a significant role in gathering, analysing, and periodically publishing consolidation at EU level of NWA's results, as long as there is a common agreed approach and methodology.

It is also recommended demographic study including staff mobility is considered as part of the National Nuclear Workforce Assessments. The data from the National NWA's will allow for gathering of data and assessing the demographic situation of the nuclear sector at EU level.

Consolidation at EU level would also help on the way to **harmonise training and certification among EU countries** , as our study has evidenced in particular in the following areas:

- There is a need for standardisation and harmonisation of certification systems of **professionals within the medical field using ionising radiation** (physicists, radiochemists/radiopharmacists). Specific efforts are currently underway by professional organisations (such as EFOMP in the field of applications of medical physics), but these efforts need to be supported by future EU legislation.
- **Harmonizing E&T at EU level in the field of nuclear safety**, through offer of training opportunities at the European level, aligning training programmes and competences assessment for example, can improve consistency, share best practices, and ensure that the highest safety and security standards are met everywhere, recognizing that legal and regulatory framework can be different in each country. This would also eventually lead over time to simplified European licensing procedures with significant benefits for industry.

For EU policymakers, **funding and financing** is on top of the file to make recommendations real. Policymakers should recognize the importance of research and development (R&D) in the nuclear sector and increase investment in relevant initiatives. It should be remembered that **nuclear research institutes are a reservoir of skills to which other players in the sector turn to recruit experts**. Support should be also given to **education and training infrastructure**. To achieve these objectives, **EU policymakers should explore possibilities and good practices under existing initiatives and funding programmes**, such as the Euratom R&T Programme, Horizon Europe Framework Programme, Erasmus+ Programme, the European Social Fund Plus, and the Recovery and Resilience Facility.

Strengthening collaborations, mobility, and exchanges among students, doctoral candidates, and post-docs will foster knowledge sharing and skill development in the nuclear sector.

7.2 Other recommendations from the reports of the taskforces

7.2.1 For industry

To optimize talent acquisition and retention, companies within the nuclear sector should **collaborate and share best practices at the EU27+UK level rather than compete unnecessarily for skilled individuals**.

7.2.2 For safety organizations (regulators and technical safety organizations)

Maintaining sufficient manpower and expertise for the safety of all nuclear activities is the top priority. Particular attention should be paid to the preparation of their competences, in particular for innovative technologies, where efforts could be greater and require a longer period. Training at European level, with at least partly harmonized curricula, should be deeper examined.

7.2.3 For universities and research organizations

The last 30 to 40 years have shown important changes in the curricula of the universities 'studies and in priorities of research organizations. Fundamental scientific units have often been wiped out from the curricula all over the world. R&D followed the same trend, being more directed to reactors designs, fuel assemblies, since the research drive (and fundings) of the companies prioritize applied engineering topics.

In this context universities and research organizations have to face potentially contradictory guidelines in building their E&T offer or R&D programmes: keep scientific level of graduated students at top level in basic disciplines, keep R&D results at top of international state of the art, according to peers reviews criteria, while simultaneously, as recommended in this report, increase connection with industry priorities and follow the trend required towards multidisciplinary curricula.

7.2.4 For the medical sector

The main question in this sector, leading to most of the recommendations, is how to correct high variability observed among EU countries. Funding residency programmes in the 27 EU member countries would be one way to reduce the variability in the training of medical physicists currently observed.

The current efforts at european level (EFOMP in collaboration with other organisations such as ESTRO, ESR, EANM) to revise the core curricula of medical physics experts within the different specialities concerned by the use of ionising radiation (radiotherapy, nuclear medicine, diagnostic radiology) aims at creating a common and unique curriculum for the training of MPEs in Europe. This may help towards a common certification of MPEs in the EU27+UK.

New topics such as artificial intelligence (AI) should be considered in further revision of curricula for nuclear medicine and radiology